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(71) Applicant: DANFORTH BIOMEDICAL, INC. [US/US]; 1505 Adams Drive, Suite D, Menlo Park, CA 94025 (US).

(72) Inventors: MATANI, Nitin ; 5278 Country Oak Court, San Jose, CA 95136 (US). CIERKOSZ, Zbigniew ; 2602 Hambleton Lane, Santa Cruz, CA 95065 (US).

(74) Agents: HEINES, M., Henry et al.; Townsend and Townsend, One Market Plaza, 2000 Steuart Tower, San Francisco, CA 94105 (US).

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(54) Title: IMPROVED BALLOON CATHETER OF LOW MOLECULAR WEIGHT PET

(57) Abstract

Balloon catheters are formed from low molecular weight polyethylene terephthalate with an intrinsic viscosity of 0.9 dL/g or less by placing tubing of such material in a mold cavity whose diameter exceeds that of the tubing by the desired degree of expansion, and pressurizing the tubing while heating the mold to a temperature exceeding both the first and second order transition temperatures of the PET from which the tubing was made, so that the tubing expands to fill the mold cavity. The resulting balloon is characterized by an unusually high toughness combined with superior flexibility and softness of feel.

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IMPROVED BALLOON CATHETER OF LOW MOLECULAR WEIGHT PET

This invention is in the field of polymeric materials and their use in medical devices, and relates particularly to the manufacture of balloon catheters.

BACKGROUND OF THE INVENTION

Balloon catheters are widely used in medical procedures and are well recognized for their ability to correct various types of internal problems without invasive surgery. The operation and use of a balloon catheter involves insertion of the catheter into the body vessel where treatment is to be performed, followed by expansion of the balloon section by pressurized fluid. Qualities which the balloon must have for the catheter to function effectively are that it be readily expandable despite being made of inelastic material, and readily collapsible as well to permit removal from the body vessel when the procedure is completed. This is particularly true for balloon catheters designed for relieving arterial stenosis and for other procedures inside blood vessels. The balloon must be sufficiently flexible to fully and rapidly expand when pressurized, and yet sufficiently tough to withstand the high pressure without rupture.

The handling of a balloon catheter is a very delicate matter, since careless handling can create tears which can remain unnoticed until the catheter is pressurized. Openings in the balloon wall can result in high pressure fluid entering the artery or other vessel in which the catheter has been inserted. This can cause internal injuries to the patient as well as a loss of pressure inside the catheter. Similarly, rough surfaces caused by mishandling can cause injury to the internal vessel wall. The balloon must therefore be flexible to respond rapidly to inflations and deflations and yet sufficiently tough and durable to withstand

these changes and the stress of a high pressure differential without damage to the balloon wall.

SUMMARY OF THE INVENTION

It has now been discovered that a balloon catheter with an unusual combination of durability and toughness on the one hand and flexibility and softness to the touch on the other is achieved from a low molecular weight polyethylene terephthalate (PET), in a process which involves expanding a length of tubing of the PET by pressurizing the tubing interior at a temperature which is above both the first and second order transition temperatures of the PET.

While it was heretofore believed that high molecular weight PET and the high tensile strength which is inherent in such a material was necessary to form a sufficiently tough balloon catheter, the present invention establishes that low molecular weight PET can be used effectively, and is in fact superior since it offers significant benefits as well which are not achievable with the high molecular weight material. While its tensile strength may be lower, the balloon formed from the low molecular weight PET has greater toughness, which is the integral of tensile strength *vs.* elongation, rendering the balloon less susceptible to the formation of tears or weak spots. The resulting product is easier to handle, safer to use and more durable.

A related discovery is that, unlike higher molecular weight materials, the low molecular weight PET does not need to be biaxially oriented in the balloon formation process to achieve a sufficiently durable balloon. Expansion to form the balloon can be thus confined to the radial direction (or "hoop" expansion), rather than a combination of the axial and radial directions, with no loss in beneficial properties.

Other features and advantages of the invention will become evident from the description which follows.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

Due to the inexactness and spread of the molecular weight for any given sample of PET, the intrinsic viscosity of PET is conventionally used as a measure of its molecular weight. Intrinsic viscosity η_i is derived from the actual viscosity of a solution of the polymer by calculating the relative viscosity η_r, which is the ratio of the viscosities of the solution and the solvent, subtracting 1 from η_r to achieve the specific viscosity η_{sp}, dividing η_{sp} by the concentration of the solution to achieve the reduced viscosity η_{red}, and extrapolating η_{red} to zero concentration. The determination is generally made at 25°C or a temperature in the vicinity thereof, and the units of intrinsic viscosity are deciliters per gram (dL/g).

The PET used in accordance with the present invention may therefore be characterized by an intrinsic viscosity of about 0.9 dL/g or less. This corresponds approximately to a number average molecular weight of about 43,000. In most cases, best results will be obtained with PET having intrinsic viscosity in the range of about 0.6 dL/g to about 0.9 dL/g (corresponding approximately to a number average molecular weight range of 24,500 to 43,000), and preferably about 0.65 dL/g to about 0.8 dL/g (number average molecular weight of 27,500 to 36,500). One example which has been used effectively is PET with an intrinsic viscosity of about 0.72 dL/g, corresponding approximately to a number average molecular weight of 31,600. All intrinsic viscosity values herein refer to 25°C.

In the practice of the present invention, the PET is first supplied as a length of hollow tubing, formed by any conventional manner. Extruded tubing is a prime example. The crystalline state of the PET in the tubing is not critical and may vary, although it must be consistent throughout any single extrusion run and from lot to lot. Amorphous PET is acceptable and is also preferred.

The tubing diameter and wall thickness will vary with the dimensions desired for the finished balloon, and are

otherwise not critical. A typical range for wall thickness is about 0.005 inch (0.013cm) to about 0.050 inch (0.127cm), with preferred thicknesses falling within the range of about 0.008 inch (0.020cm) to about 0.020 inch (0.051cm). A typical range for tubing outer diameter is about 0.01 inch (0.025cm) to about 0.10 inch (0.25cm), with preferred diameters falling within the range of about 0.02 inch (0.051cm) to about 0.05 inch (0.13cm).

The balloon is formed by expansion of a segment of the tubing in the radial direction to a preestablished or preselected expanded diameter. This is achieved by placing the tubing in a mold cavity which has the desired shape and dimensions of the final balloon, pressurizing the interior of the tubing and heating the mold to cause the tubing in the cavity to soften and expand to fill the cavity. During this expansion, the radially directed pressure causes the tubing wall to be stretched in the direction along the tubing circumference, perpendicular to the tube axis. This is referred to as the "hoop" expansion, and is distinguished from axial expansion or the longitudinal stretching of the tubing. With amorphous tubing as the starting material and only hoop expansion being performed, the finished balloon will lack biaxial orientation of the crystal structure, at least to any appreciable degree that might have a bearing on the properties of the finished balloon.

The degree of expansion can be varied and is not critical. In most cases, expansion will be performed to result in an increase in the outer diameter of the tubing to a degree ranging from about 2.0 times to about 10.0 times the unexpanded diameter, preferably from about 3.0 times to about 6.0 times.

The length of the segment of tubing which is expanded to form the balloon is not critical and does not affect either the process or the product which is formed. In most cases, the balloon will be from about 1 inch (2.54cm) to about 3 inches (7.6cm) in length.

The pressure exerted inside the tubing during the expansion is not critical, and subject only to the limitations

of the mold. In most applications, the pressure will generally lie within a range such as about 100psi (gauge) to about 200psi, although a range of about 120psi to about 160psi is preferred.

The temperature to which the tubing is heated to cause it to expand in accordance with this invention is a temperature which is about 20°C or more above the first order transition temperature of the PET.

Like the intrinsic viscosity, the first and second order transition temperatures are further means of characterizing the PET used in the practice of this invention and distinguishing it from PET's which differ in average molecular weight, molecular weight distribution or both. The second order transition temperature is the lower of the two, and both are lower than the melt temperature. In preferred embodiments of this invention, the first order transition temperature is less than about 90°C, and in more preferred embodiments, it is from about 70°C to about 80°C. Likewise, in preferred embodiments, the second order transition temperature is from about 40°C to about 65°C, and in more preferred embodiments, from about 50°C to about 60°C.

Preferred processing temperatures are those which exceed the first order transition temperature by from about 20°C to about 80°C. Particularly preferred temperatures are those exceeding the first order transition temperature by from about 30°C to about 50°C. Tubing made from PET with a first order transition temperature of about 73-77°C and a second order transition temperature of about 55°C has been used with success with a processing temperature of about 115-121°C.

The mold in which the tubing is expanded when forming the balloon will be in the form of a hollow tube of sufficient diameter to permit insertion of the PET tubing. The mold cavity will be an expanded portion of the hollow tube whose diameter will equal the diameter to which the PET tubing is to be expanded along the portion forming the balloon, and whose length will correspond to the desired length of the balloon. Preferably only this expanded portion will be heated during the pressurization and expansion of the PET tubing. At

either end of this expanded portion will be a narrow bore segment which will hold the PET tubing in the center of the expanded portion so that the tubing will expand uniformly in all radial directions. The narrow bore segment on one side may be of somewhat larger diameter to permit the balloon once formed (although flattened out due to the removal of internal air pressure) to be removed from the mold.

The mold may be constructed of any material which is inert to the PET, and can withstand the pressure exerted upon the PET tubing from inside. The mold cavity must also have sufficient surface smoothness to produce a balloon having a texture which is smooth and soft to the touch, to minimize the possibility of the formation of weak spots in the balloon wall and to form a balloon which can be inserted into the artery or other body vessel with a minimum of resistance. A transparent mold offers the advantage of permitting the operator to monitor the insertion of the tubing and the expansion process. Glass is a useful material in this regard, although a wide array of other materials and types of materials may be used as well.

The mold may be heated in any of a variety of ways, subject only to the need to avoid excessive heating at any particular point along the tubing, and to assure full heating of all portions of the tubing in the mold cavity. The entire mold may be placed inside a heating unit or immersed in a heated heat transfer medium to heat all portions of the mold cavity simultaneously. Alternatively, particularly in the case of a transparent mold such as glass, the mold may be slowly drawn through or past a heating element, such as for example through a resistance heater, whereby heat application is begun at one end of the mold cavity and slowly progresses to the opposite end, with the balloon expansion proceeding simultaneously. The expansion, which will start at one end and progress to the other, is readily monitored in this manner. For tubing of the dimensions cited above, a typical drawing rate is approximately 2.0-2.5cm/min. In each of these methods, the pressure is maintained inside the tubing while

the heat is applied so that the tubing expands as it reaches the elevated temperature of the heating unit.

Once the expansion is complete, the internal pressure is lowered to ambient pressure and the balloon is cooled. This stabilizes the crystal structure of the PET, and in particular the hoop orientation of the molecules. Cooling is readily performed in the mold cavity. Since the mold itself is being cooled at the same time, the cooling rate is controlled by the mold and is slower than it would be if the entire balloon were placed in direct contact with a cooling medium.

A balloon prepared in accordance with the procedure described above may be mounted on a suitable shaft to complete the catheter construction, the shaft being of conventional configuration and construction and the mounting being performed according to conventional techniques already in use in catheter manufacture. All other features of the procedure for constructing the catheter and of the catheter itself are conventional and substantially unaffected by the practice of this invention.

The foregoing is offered primarily for purposes of illustration. It will be readily apparent to those skilled in the art that modifications and variations in terms of both materials and methods can be introduced without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A process for forming a polyethylene terephthalate catheter balloon, said process comprising:

(a) placing in a mold cavity a length of tubing formed from polyethylene terephthalate having an intrinsic viscosity of about 0.9 or less;

(b) pressurizing the interior of said tubing at a temperature which is higher than the first order transition temperature of said polyethylene terephthalate by at least about 20°C, to radially expand said length of tubing to fill said mold cavity;

(c) cooling said tubing so expanded while still pressurized, to stabilize said tubing in an expanded state.

2. A process in accordance with claim 1 in which step (b) is conducted at a temperature which is higher than the first order transition temperature of said polyethylene terephthalate by from about 30°C to about 50°C.

3. A process in accordance with claim 1 in which said length of tubing is formed from polyethylene terephthalate having a first order transition temperature of from about 70°C to about 80°C.

4. A process in accordance with claim 1 in which said length of tubing is formed from polyethylene terephthalate having a second order transition temperature of from about 50°C to about 60°C.

5. A process in accordance with claim 1 in which said length of tubing is formed from polyethylene terephthalate having an intrinsic viscosity of from about 0.65 to about 0.8.

6. A process in accordance with claim 1 in which step (b) comprises pressurizing the interior of said tubing to a pressure of from about 100psi to about 200psi.

7. A process in accordance with claim 1 in which step (a) comprises placing said length of tubing in a cavity of a glass mold.

8. A process in accordance with claim 1 in which the cross sections of said mold cavity and said length of tubing are such that an expansion ratio of about 3.0 to about 6.0 is achieved in step (b).

9. A process in accordance with claim 1 in which axial expansion of said tubing is substantially avoided.

INTERNATIONAL SEARCH REPORT

ernational application No.
PCT/US92/03549

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :B29C 49/00
US CL :264/523
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 264/535,537,538,540,542,543

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,963,313 (NODDIN ET AL.) 16 October 1990, entire document.	1-9
A	US, A, 4,145,466 (LESLIE ET AL.) 20 March 1979.	
A	US, A, 4,550,007 (OHTSU ET AL.) 29 October 1985.	
A	US, A, 4,443,399 (TAKASHIGE ET AL.) 17 April 1984.	
A	US, A, 4,066,729 (VAN CAPPELLEN) 03 January 1978.	
A	US, A, 4,820,349 (SAAB) 11 April 1989.	
A	US, A, 4,950,239 (GAHARA ET AL.) 21 August 1990.	
A	US, A, 4,941,877 (MONTANO, JR.) 17 July 1990.	
A	US, A, 4,490,421 (LEVY) 25 December 1984.	

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
14 AUGUST 1992	15 SEP 1992

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ternational application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	P.L. Heater, "Polyethylene Terephthalate: Pet," Modern Plastics Encyclopedia , published 1987 by McGraw Hill (N.Y.), pages 44, 46.	
A	SEYMOUR ET AL., "Polymer Chemistry", 2nd edition, published 1988 by Marcel Dekker, Inc. (N.Y.) page 32.	